Forecasting Research Division
Technical Report No. 34

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Assessment of the bias of significant wave height in the Met. Office global wave model

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Abstract

Routine comparisons are made between the wave heights hindcast and forecast by the global wave model and those from wave buoys and platforms. Considering the verification figures as a time series shows that wave heights in model hindcasts have decreased steadily during the life of the wave model, relative to the buoys. A similar decrease is found in the wind speeds analysed by the weather forecast model. There is an increase in wave heights during the forecast period. The decrease of wave height in hindcasts appears from circumstantial evidence to be associated with changes in the weather forecast model analysis technique. It is recommended that the surface winds from SHIP reports, which are used by the data assimilation scheme, are applied to the model at the correct height.

Introduction

The Met. Office runs two operational wave models. One is run globally, and the other covers the European Shelf waters and the Mediterranean Sea. Both models are based on the same computer code, but the "European" model includes additional physical processes appropriate to shallow waters. Although there have been several changes to the wave models since they were first written, the description of Golding (1983) still gives an adequate introduction to the methods used.

In 1987 there were a number of changes to the model, but after that there were no significant changes until the introduction of increased resolution in June 1992 as the operational suite transferred to the CRAY computer. Conversion of the model to run on the CRAY did not introduce any intentional changes to the physics of the wave model, and the only significant error found in the code since then was incorrect treatment of spatial smoothing. In October 1992, changes were made to the model to improve its representation of swell energy and which greatly improved the skill of the wave model (Holt, 1992), in trials using data for a standard test case of November 1988.

The wave model is run operationally as a sequence of "hindcasts" followed by a forecast. These hindcasts take the place of analyses, and no data assimilation into the wave model was done during the period covered by this report. Winds used to drive the hindcasts were extracted from the assimilation cycle of the weather forecast models; those used to drive the forecast were taken from the weather forecast.

After the wave model had run on the CRAY for several months, the operational division of the Met. Office noticed that the bias of the wave model, relative to buoy observations, was worse than on the CYBER computer and asked for an explanation. This document is the response of the wave modelling group to that request. Several aspects of the bias in wave heights are discussed. First the trend in the annual mean bias is examined. This is then broken down into a month by month analysis of the bias to show when the changes happened. Next the seasonal cycle of the errors is discussed, then the spin up of wave heights during the forecast period. The next section suggests how the use of observations in the analyses might contribute to the errors in wave height found in the wave model hindcasts and forecasts. Finally, recommendations are made for changes to the observation pre-processing in the weather forecast suite to improve the performance of the wave models.

Annual mean time series of wave height bias.

Routine verification of wave heights of the global wave model compares the wave model output with 34 wave buoys, 1 weather ship and 5 platforms, from which observations are received in real time. The verification figures are thus dominated by those for the buoys, and for simplicity the following discussion assumes that buoys are the only contributors to the verification archive.

Figure 1 shows the trend in annual mean bias of the global wave model. The statistics are broken down by the observed wave height and the overall trend is shown on the right of the figure. Immediately obvious is a decrease with time of wave height of the model relative to the buoys. This is found for all wave heights, and is surprisingly linear for low wave heights, for which the model heights decreased by 10 cm each year relative to the wave buoys. Before 11 September 1988 the buoys reported wave heights to the nearest 0.5m; since then they have reported to the nearest 0.1m. Over the period 1987 to 1991 the wave model average wave height decreased by 47cm relative to the buoys. This trend is disturbing and difficult to explain if only the wave model is considered.

An immediate hypothesis which could explain the trend is that a replacement programme for the buoys might have introduced new instruments with different characteristics. This hypothesis was rejected during the study because no evidence could be found for a systematic buoy replacement programme, and because neither NMC nor FNOC (Monterey) could find a similar trend in the verification of their wave models. The trend must, therefore, have arisen from the Met. Office forecast system itself.

Wave models are very sensitive to the accuracy of the wind fields used to drive them (a rule of thumb is that a 10% difference in wind speed produces a 20% difference in wave height). Winds for the Met. Office global wave model are derived from the global numerical weather prediction (NWP) model and correspond to the lowest level in the weather forecast model (23m). Figure 2 shows the trend in bias of the analysed winds relative to the buoys. The decrease of wind speed is more erratic than that of wave height. Nevertheless, the reduction between 1987 and 1991 of $0.5ms^{-1}$ is enough to explain a reduction in wave height of almost 0.4m (assuming a global mean wind speed of $7.5ms^{-1}$).

At first sight, the trend of the wind bias is to improve the analysed winds, and the immediate implication is that the wave model is responding poorly to the improved wind field. This is wrong. Operational verification for the global wave model takes no account of the height of the observed winds. Thus winds from a wave buoy (with its anemometer at a height between 2m and 5m) are compared with the lowest level winds from the atmosphere model (which correspond to a height of 23m). The model winds should, therefore, be stronger than those reported by buoys, by over 10%. Weather ship GACA reports a 10m wind speed used for verification. Only for the 5 platforms should the model winds be lighter than observed. The overall verification scores should be determined by the buoys, however, and thus the analysed wind speed should exceed the observed speed. The consequence of this argument is that analysed wind speeds are too light and instead of representing the wind at 23m, the analyses represent the winds at less than 5m.

Monthly statistics

It is impossible to find even circumstantial evidence for the cause of the reduction in model wave heights from the annual mean verification statistics. Figure 3 shows the monthly biases from 1987 to 1992. Although the downward trend is still clear, the monthly figures show that the accuracy of the wave model decreased in steps. These happened around April 1988, December 1988, April 1989, and January 1991. Before June 1991 there was almost no seasonal signal to the verification figures, but it is clear that during winter 1991/2 the skill of the wave model hindcasts was worse than during the summers either side.

Figure 3 is annotated with changes to the weather forecast system which were published in the *Quarterly Report on Numerical Products from Bracknell*. With the exception of the decrease in skill of April 1989, the wave model accuracy decreases were associated with changes to the atmosphere model analysis system. Figure 4 shows the verification of wind speed against observations. Although masked by the seasonal cycle of errors, there is a trend to weaker winds (relative to observations) in winter months.

It is already clear that the wave model is the slave of the atmosphere model. The decrease in accuracy of the wave model reflects the steady decrease in skill of the atmosphere model analyses.

Seasonality

Although the wind verification in fig. 4 shows evidence for a seasonal cycle in the skill of the models, even the skill of the wave model is affected by the seasonal cycle on the CRAY (fig. 3). Seasonal variation of accuracy of the wind speed from the global Unified Model is very clear in fig. 5 which compares ERS-1 wind speeds with those from the weather forecast model's analyses for the oceans north of 45°N. Unlike the operational verification, the model wind speeds were reduced to 10m before the statistics were generated. Thus, in this diagram, perfect winds correspond to zero bias. Although confused by the frequent changes to the operational suite, the trend for model wind speeds to be too low in winter and too high in summer is clear.

Figure 6 compares wind speed distributions from ERS-1 and the model for February 1992. It is clear that high wind speeds are forecast with similar frequency as the altimeter observed them, and that the model preferred speeds between $2.5ms^{-1}$ and $5.5ms^{-1}$ at the expense of lower and higher wind speeds. It

appears that the extreme wind events are handled effectively by the weather forecast model, but that the distribution for moderate wind speeds is poorly represented. It is therefore to be expected that the distribution of wave heights is strongly biased towards low wave heights (fig. 7).

Comparing the model analyses with ERS-1 observations has a major advantage over comparing with other sources of data. During the period discussed in this report, ERS-1 wind speeds and wave heights were not assimilated into the models, and therefore act as an independent assessment of the model performance (of course, the ERS-1 data were themselves being assessed during this period for their own accuracy).

Spin up

So far, this paper has only discussed the winds from the analyses produced by the weather forecast system. On the basis of circumstantial evidence the analysis process has been accused of degrading the performance of the wave model. If the analysis is at fault, and not the forecast model, the bias of wind and wave forecasts should improve as the forecast period lengthens. Figure 8 supports this. Remembering that the global mean wind speed at 10m is about $7ms^{-1}$ and assuming that the model wind speeds should overestimate the observed values by over 10% shows that the forecast winds are indeed an improvement over those analysed (at least until day 3).

Use of surface observations

NWP analyses use winds reported in SHIP code. Many of the wave buoys used to verify the wave model report their observations in this code. Winds in SHIP reports are used by the assimilation scheme as if they were valid at the bottom model level. Although this is a reasonable assumption for many ships which use anemometers to make their wind observations (Taylor *et al*, 1991), this is not so for wave buoys (with anemometers between 2m and 5m), nor for those ships which use visual estimates for the wind speed (the Beaufort scale is calibrated to give a 10m wind and all UK ships are encouraged to report visual estimates of wind, even if the ship is fitted with an anemometer; Kent and Taylor, 1991). The way in which SHIP reports are used in the analyses is thus likely to degrade the surface wind analyses.

Recommendations

This paper has attempted to demonstrate the cause of the observed deterioration in skill of the wave model forecasts. No atmosphere model assimilations or forecasts have been run as part of this work, and so the conclusions drawn are at best tentative. Providing direct quantitative evidence to support the suggestions would require at least a month-long integration of the data assimilation cycle, because the wave field in the wave model takes about 20 days to reach equilibrium with changed wind statistics. Although this paper has concentrated on the analysis component of the operational system, it is equally likely that significant contributions to the error in wave model hindcasts result from errors in the atmosphere forecast model and the wave model.

If the hypothesis is accepted that the data assimilation scheme is responsible for much of the bias in wave model hindcasts, then the most effective way of improving the accuracy of the wave fields would be to improve the analysed wind field. Figure 2 demonstrated that the analyses of surface wind are close to the observed values, even though the observations correspond to a different level in the atmosphere. This suggests that an immediate improvement to the wave model forecasts would result from changes to the observation pre-processing for the atmosphere analyses. The first of the changes is recommended as a short term measure while the second is being developed. Both would need to be tested for their impact both on the atmosphere model forecasts and on the wave model hindcasts. The third recommendation is a change to the procedures for assessing the impact of changes to the atmosphere model forecast system.

Recommendation 1. This is a short term measure until the second recommendation can be implemented. Winds from SHIP reports should not be used in the atmosphere analyses unless the anemometer used to make the observation is known to be near 23m above the sea surface.

Recommendation 2. Winds reported in SHIP code should be used in a consistent way during the analysis. The observations should be referred to the same height as the model fields; either the model fields should be reduced to the observation height or the observation increased to the model height. In either case, the observation processing for the NWP system will need access to a database of observation heights for the vessels which usually report. For UK ships (callsigns Gxxx, Mxxx) the reported winds should be at 10m.

Recommendation 3. All changes to the NWP system should be assessed for their impact on the wave models, and this assessment should be taken into account when making the decision on whether to implement the change operationally. A minimum requirement is that the impact of the change on the low level wind structure should be known, possibly mimicking the wave model wind verification statistics.

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Kent, E C, B S Truscott, P K Taylor, J S Hopkins	1991	The accuracy of ship's meteorological observations. WMO Marine meteorology and related oceanographic activities report No 26.

Figure captions.

Figure 1 Bias of significant wave height in wave model hindcasts for the years 1987 to 1991. Values shown are model minus observation, in metres. The classes into which the statistics are divided are based on the observed wave height.

Figure 2 Bias of wind speed used by the wave model hindcasts for the years 1987 to 1991. Values shown are model minus observation, in ms^{-1}. The classes into which the statistics are divided are based on the observed wind speed.

Figure 3 Bias of the wave model hindcast wave height for the period July 1987 to September 1992. Bias is defined as model minus observation. The annotations show some of the changes to the NWP suite during the period.

Figure 4 Bias of the wind speed used to drive the wave model hindcast for the period July 1987 to September 1992. Bias is defined as model minus observation.

Figure 5 Bias of wind speed used to drive wave model hindcasts compared with ERS-1 radar altimeter wind speed observations. The period is December 1991 to September 1992.

Figure 6 Distribution of wind speed during February 1992. The dark shaded values are those for the model and the light ones are ERS-1 radar altimeter measurements. Bins are $0.5ms^{-1}$ wide. Model winds were converted to 10m for this comparison. The accuracy of the conversion may be assessed by noting that the peak of the distribution is in the same bin for both the model and observed wind speeds. The lowest bin contains some values at points covered by sea ice in the model.

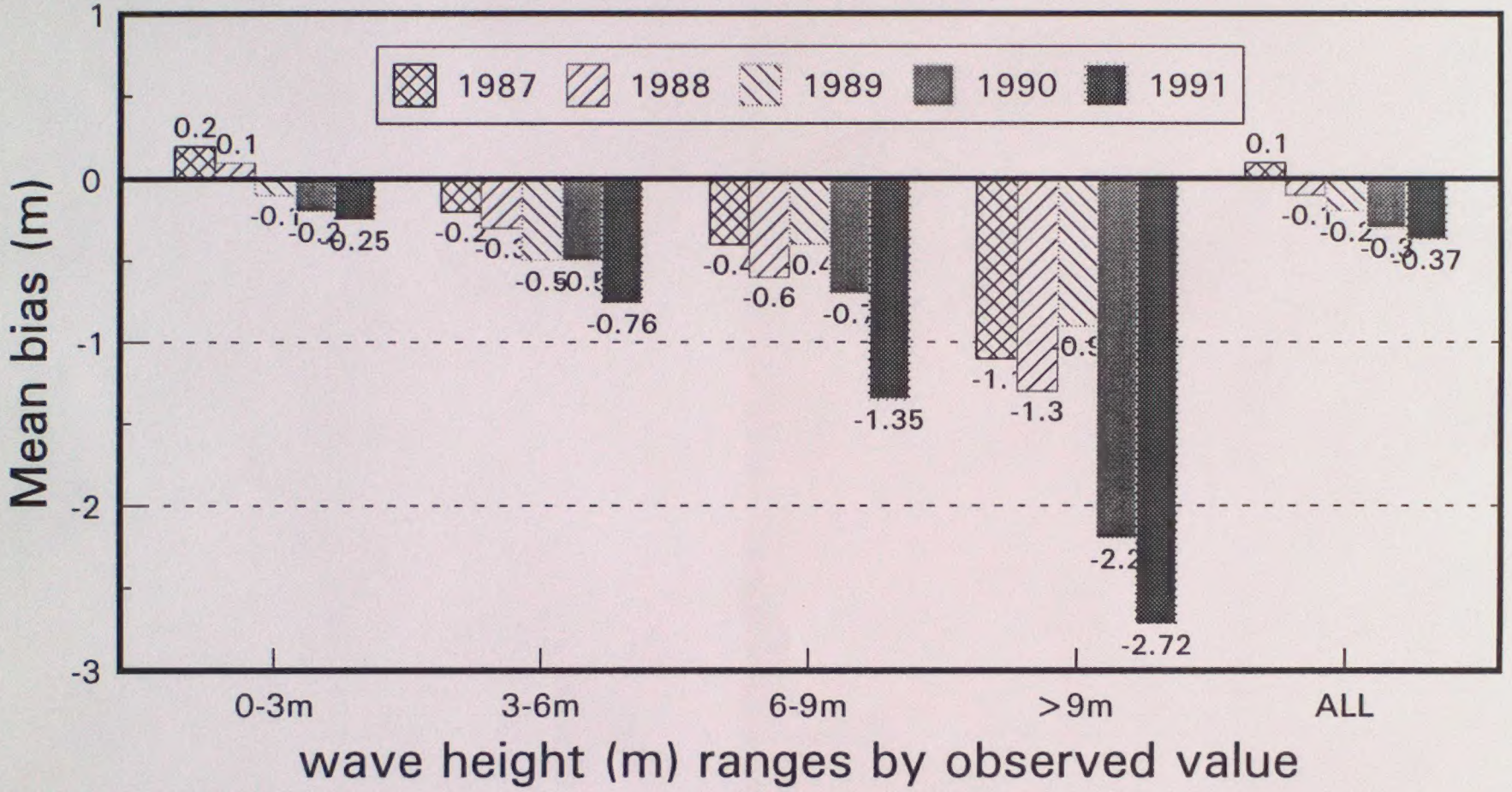
Figure 7 Distribution of significant wave height during February 1992. The dark values are for the model, and lighter values are for the ERS-1 radar altimeter. Bins are 0.5m wide. The lowest bin contains some values at points covered by sea ice in the model.

Figure 8 Bias of wind speed (a, ms^{-1}), and wave height (b, metres) as a function of forecast period. Bias is defined as model minus observation.

Wave Model Global Verification

Wave Height Mean Error at Buoy locations t+0

ANNUAL SUMMARY



Typical numbers of cases are :
31,000 8500 900 100 ALL 40000
Hts measured to 0.1m from 11/9/1988

Figure 1

Wave Model Global Verification

Windspeed Mean Error at buoy locations t+0

ANNUAL SUMMARY

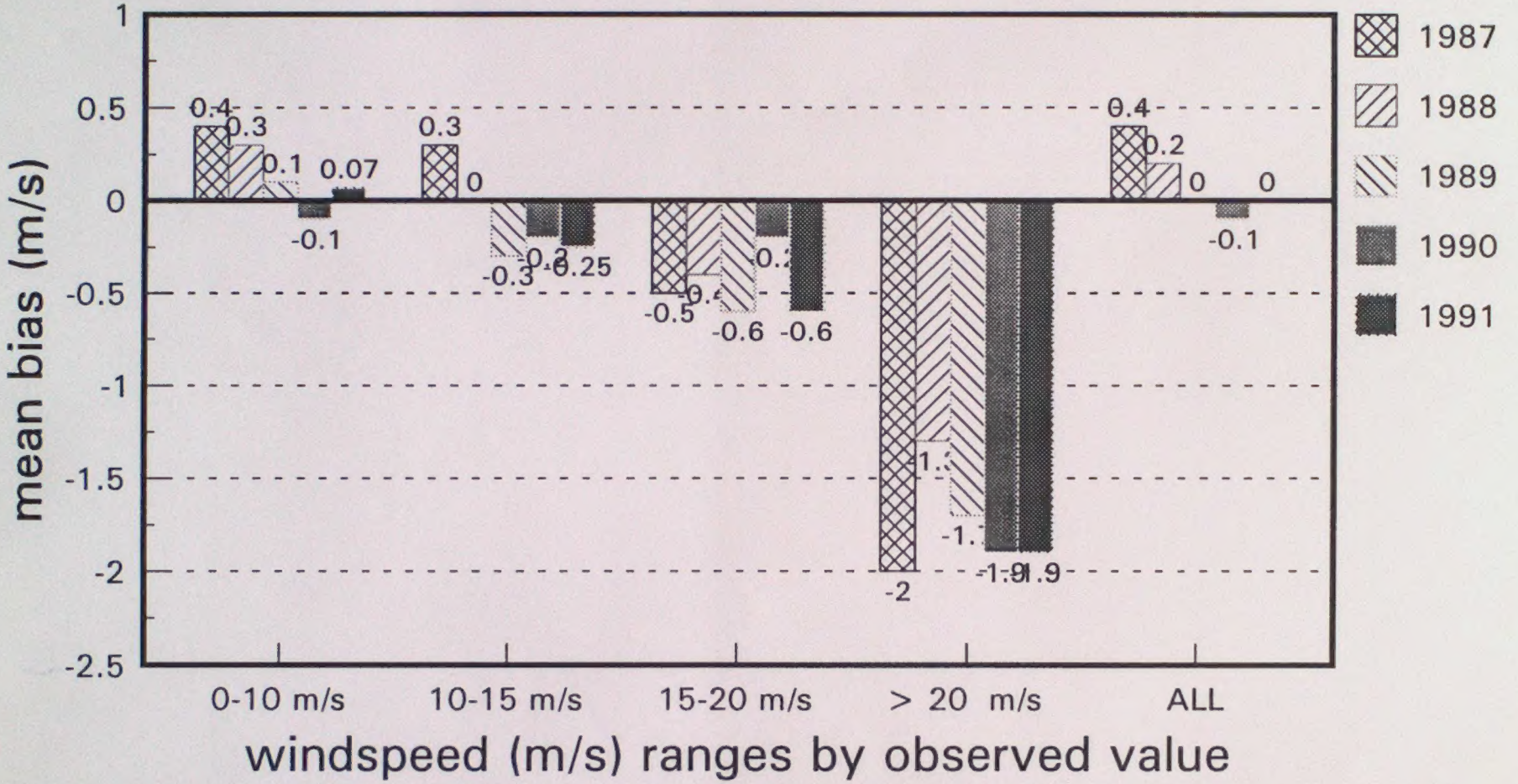


Figure 2

Typical numbers of cases are :
33000 6500 1000 250 ALL 41000
except for 1990 data when numbers are about half

Wave Model Global Verification

Wave Height Mean Error at t+0

All Stations

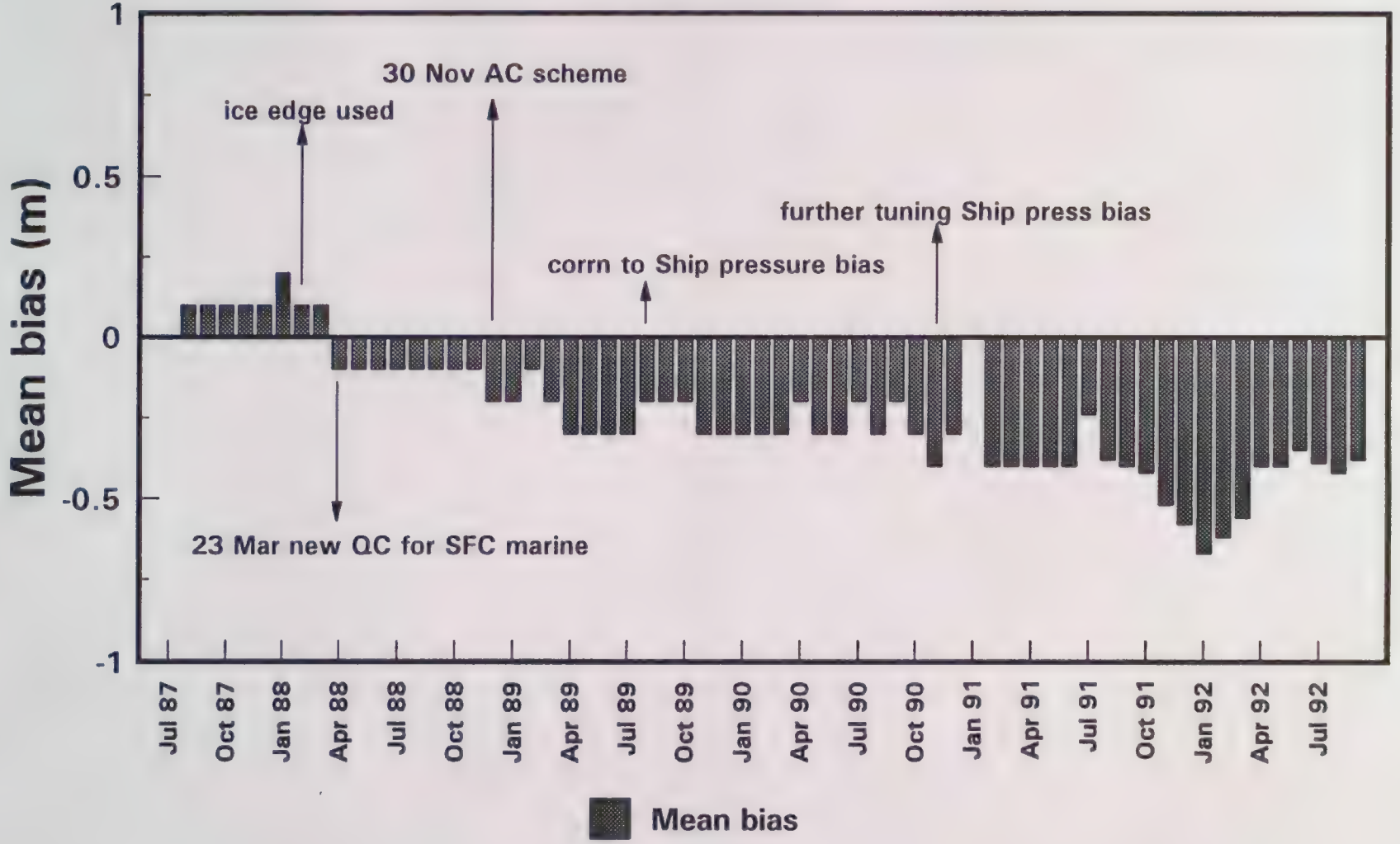


Figure 3

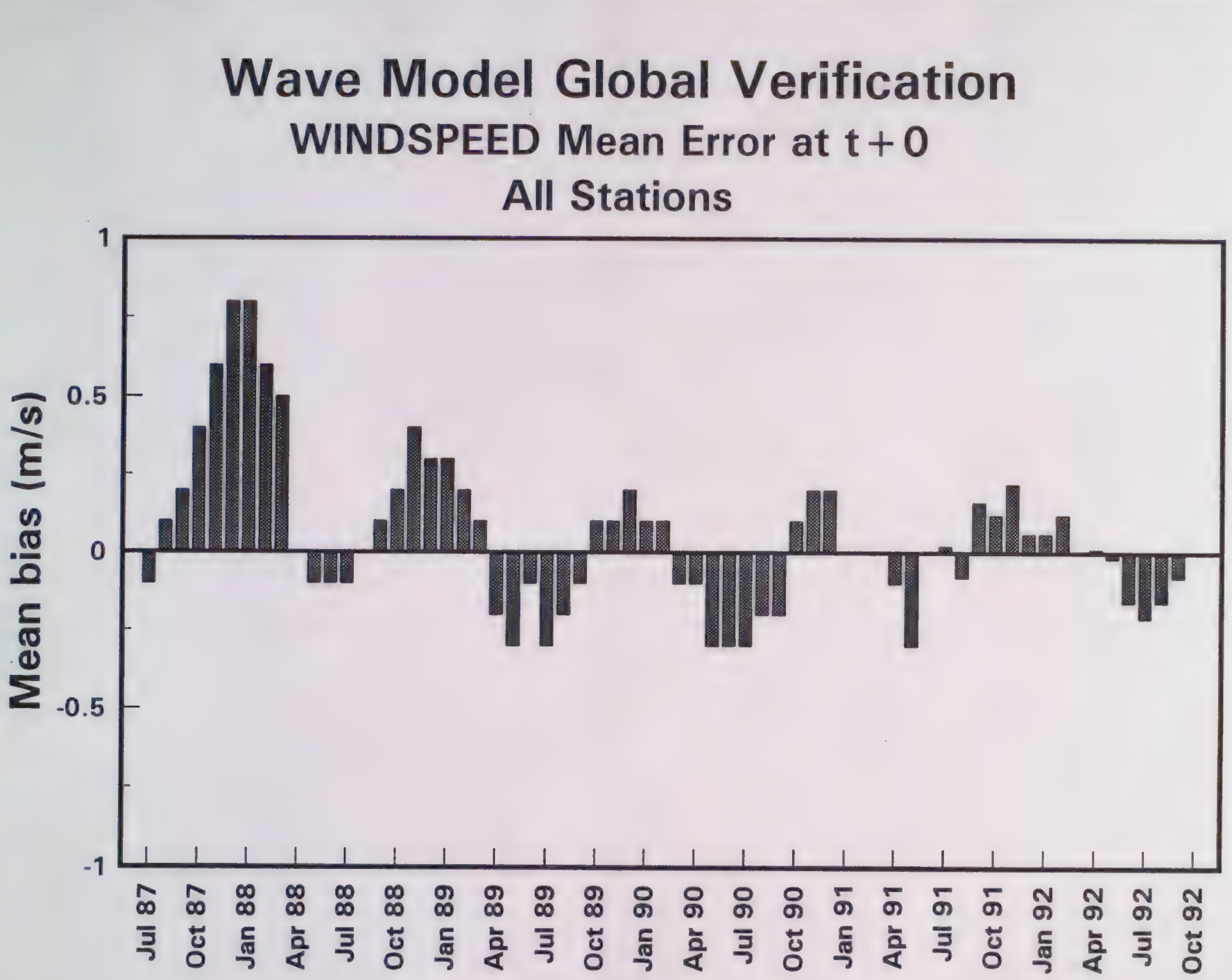
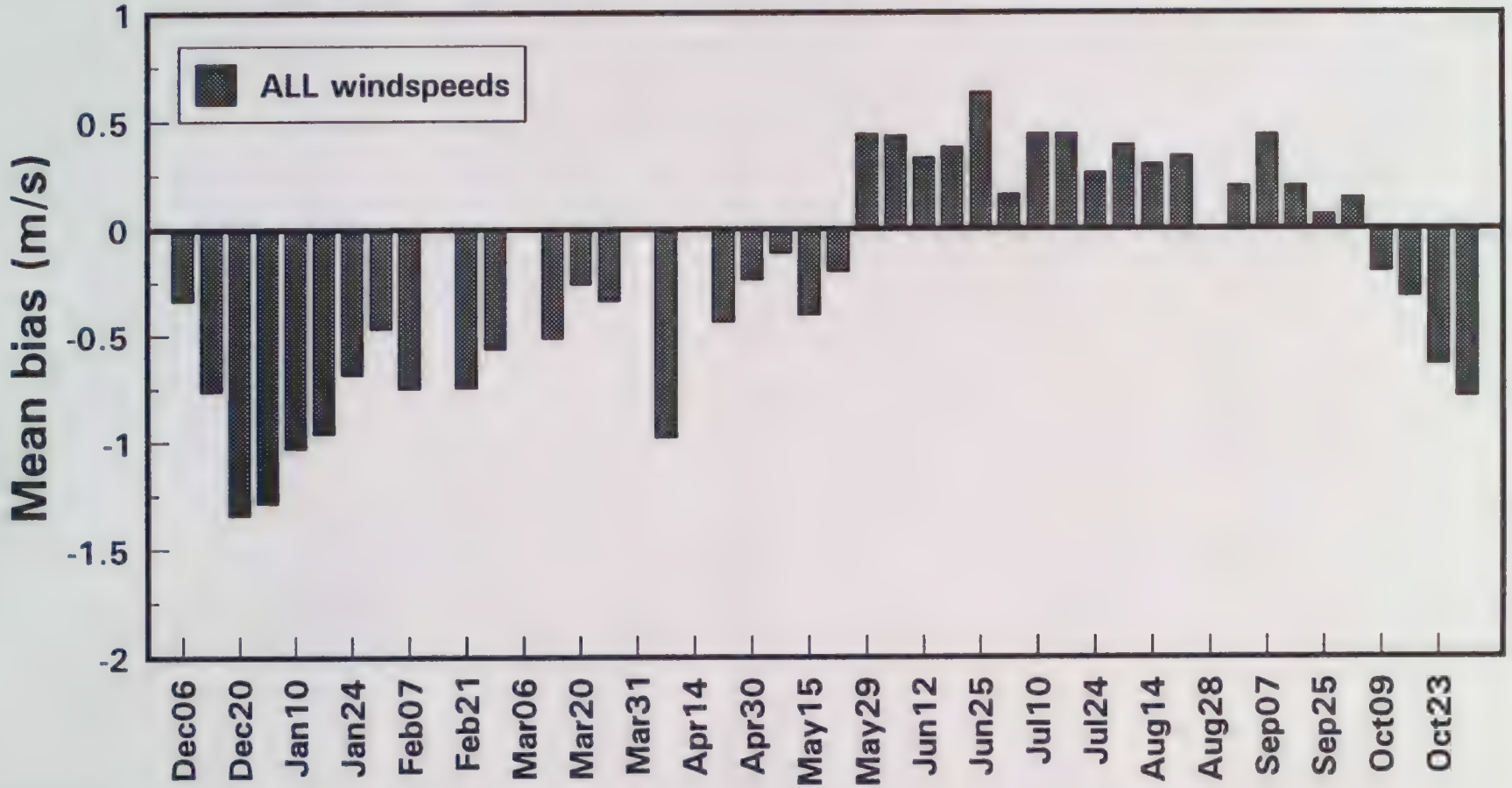

Wave Model Global Verification
WINDSPEED Mean Error at t+0
All Stations
Mean bias (m/s)
1
0.5
0
-0.5
-1
Jul 87
Oct 87
Jan 88
Apr 88
Jul 88
Oct 88
Jan 89
Apr 89
Jul 89
Oct 89
Jan 90
Apr 90
Jul 90
Oct 90
Jan 91
Apr 91
Jul 91
Oct 91
Jan 92
Apr 92
Jul 92
Oct 92

Figure 4

ERS-1 altimeter

Windspeed comparison at UKMO model SEA points

WINDSPEED Mean Bias MODEL - OBS 45N - 90N



Binned by mean (Obs + Model)

Gaps are missing data

Figure 5

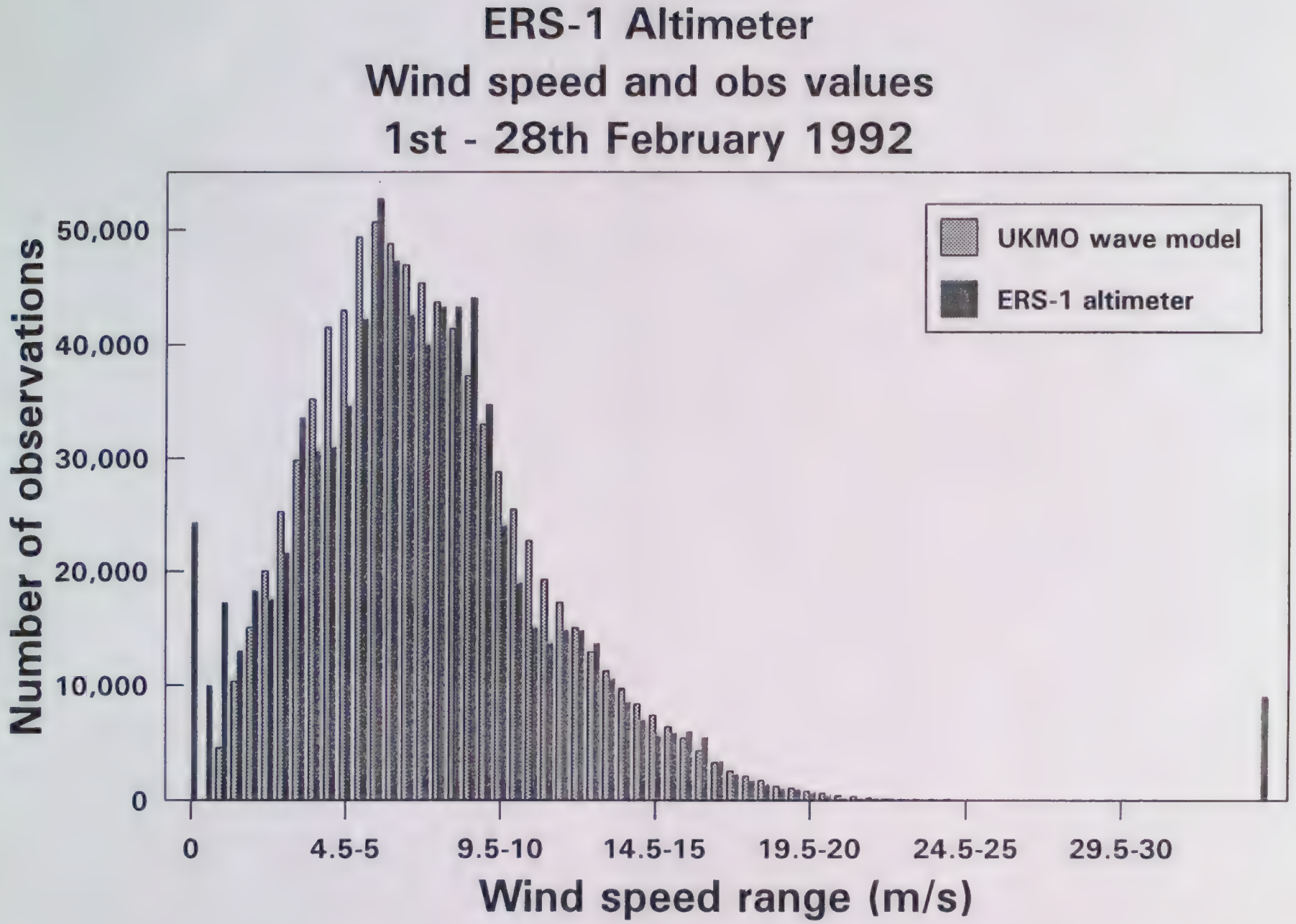

ERS-1 Altimeter
Wind speed and obs values
1st - 28th February 1992
UKMO wave model
ERS-1 altimeter
Number of observations
50,000
40,000
30,000
20,000
10,000
0
0
4.5-5
9.5-10
14.5-15
19.5-20
24.5-25
29.5-30
Wind speed range (m/s)

Figure 6

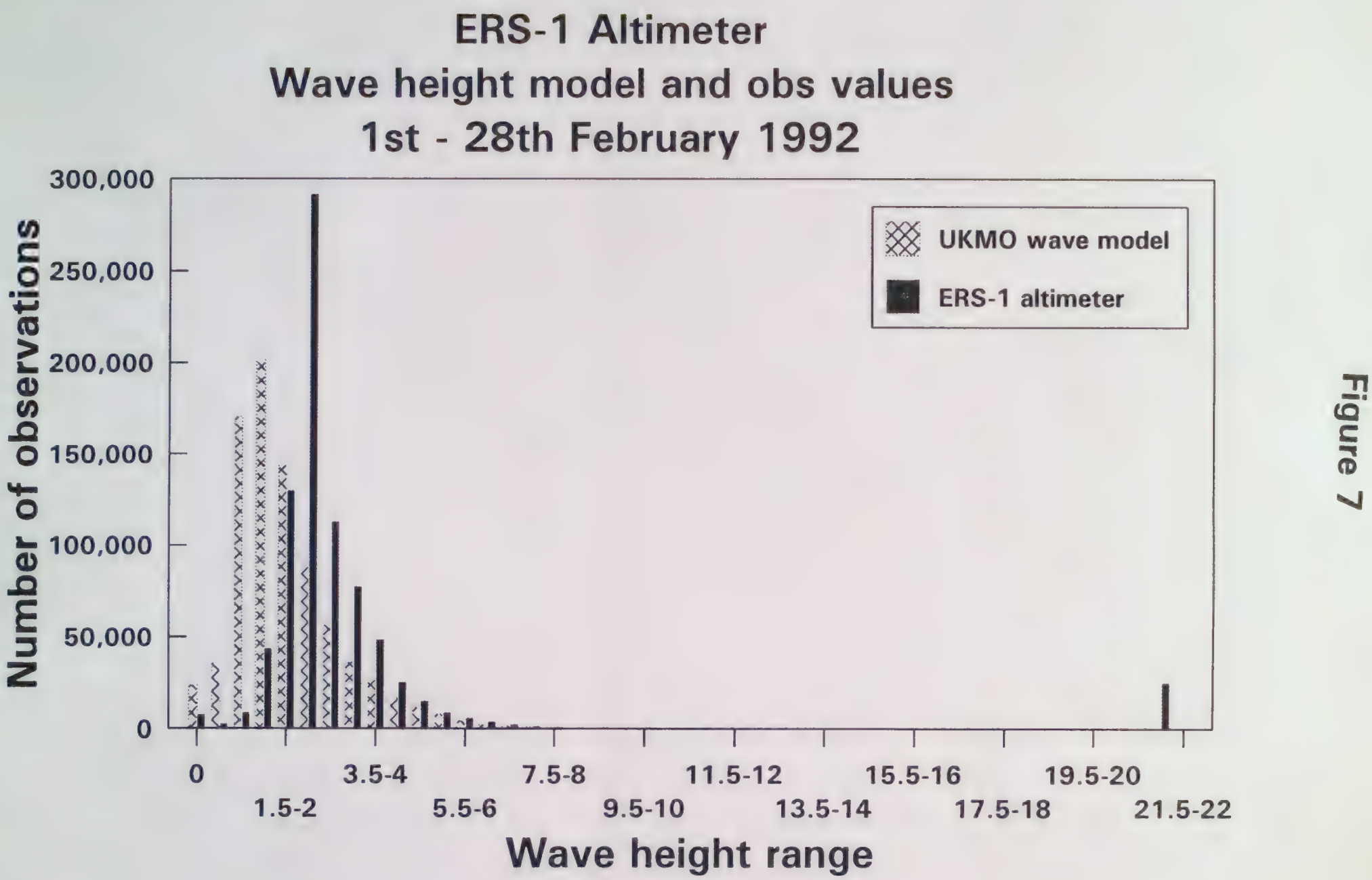
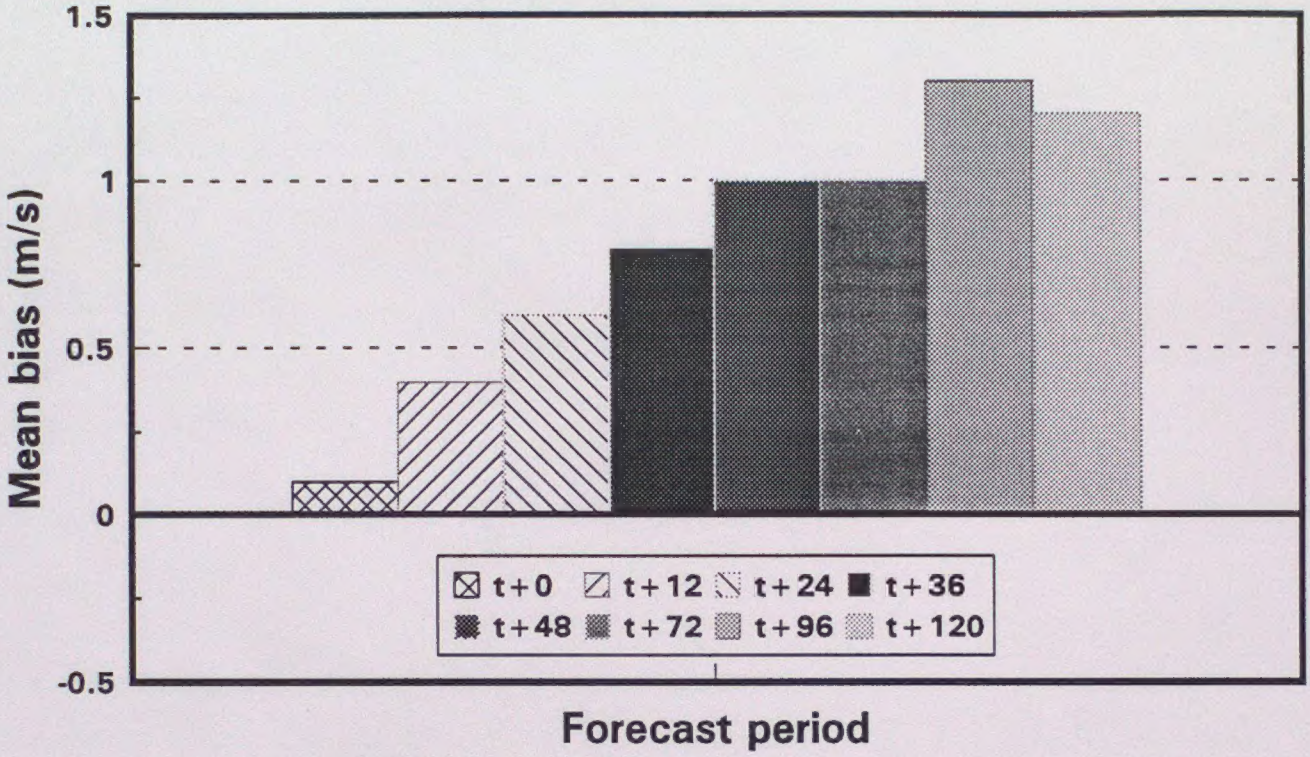

ERS-1 Altimeter
Wave height model and obs values
1st - 28th February 1992
Number of observations
300,000
250,000
200,000
150,000
100,000
50,000
0
UKMO wave model
ERS-1 altimeter
0
1.5-2
3.5-4
5.5-6
7.5-8
9.5-10
11.5-12
13.5-14
15.5-16
17.5-18
19.5-20
21.5-22
Wave height range

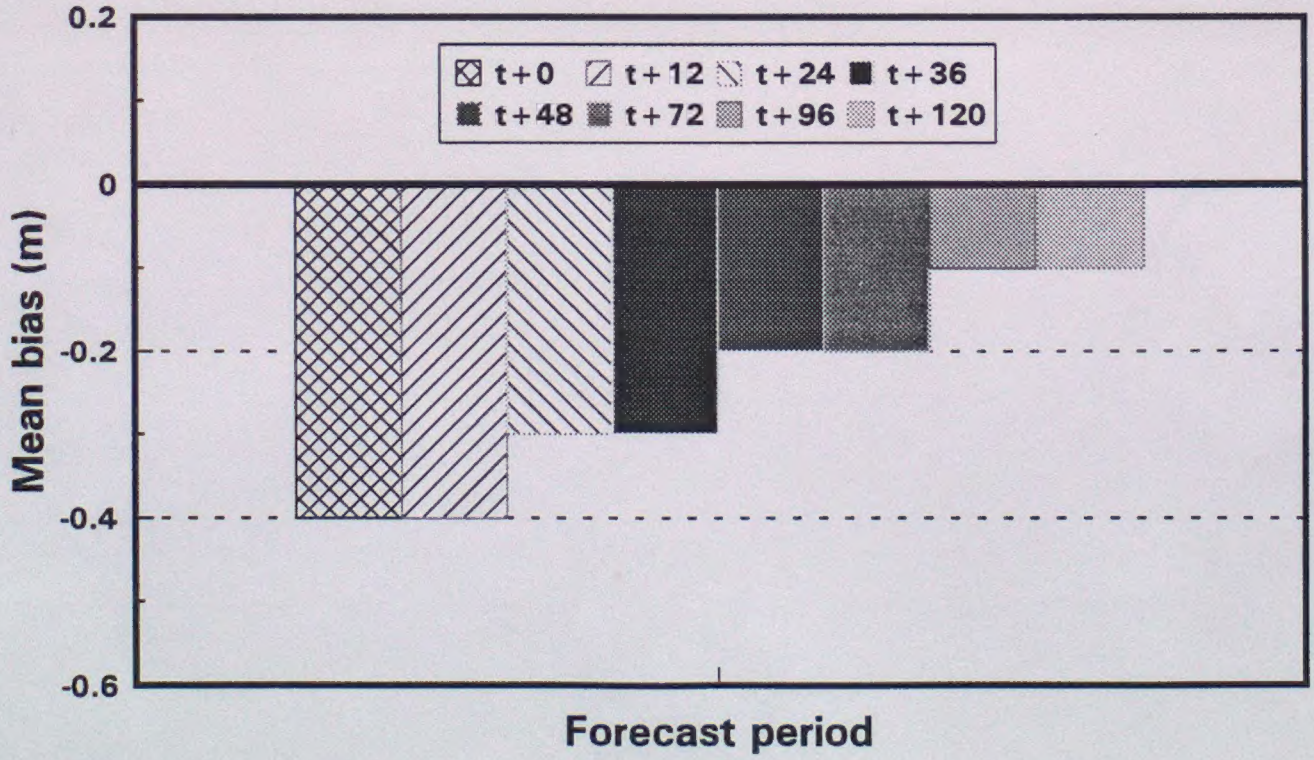
Figure 7

Figure 8

a) Windspeed by forecast period : Oct 1991



b) Wave height by forecast period: Oct 1991



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